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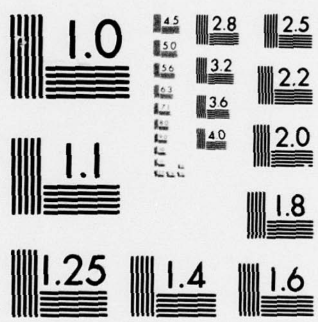

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SOLID STATE VERTICAL SCALE INDICATOR FOR ENGINE PERFORMANCE INDICATION (U)

FINAL TECHNICAL REPORT

(13 NOV. 1975 TO 28 SEPT. 1976)

OCTOBER, 1976

BY

G. M. GOZEMBA

R. L. SKOVHOLT

PREPARED UNDER CONTRACT NO. N62269-76-C-0109

FOR

NAVAL AIR DEVELOPMENT CENTER

DEPARTMENT OF THE NAVY

GENERAL ELECTRIC COMPANY

AEROSPACE INSTRUMENTS AND PRODUCT SUPPORT DEPARTMENT

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The work performed on an evaluation sample of a totally solid state engine performance instrument is presented. The particular application is a six channel indicator with each parameter displayed as a bargraph and a redundant numeric. The display medium is gallium arsenide phosphide (GaAsP) LED emitting light in the red spectrum. Emphasis is given on characteristics and the performance of an evaluation unit.

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FOREWORD

The development effort (Contract No. N62269-76-C-0109) described in this report was performed by the Aerospace Instruments and Product Support Department (AIPSD) of the General Electric Company located in Wilmington, Massachusetts. The work was sponsored by the Naval Air Systems Command (NAVAIR SYSCOM) Washington, D. C. Messrs. R. Rank, AIR-53351A and G. Tsaparas, AIR-340D provided overall program direction for the effort.

The Naval Air Development Center (NADC), Warminster, Pennsylvania, administered the contract and provided technical direction. Mr. W. G. Cole, AVTD NADC was the Naval Project Engineer for this effort. His management, V. A. Freitag and E. Rickner provided guidance in the execution of this program.

Messrs. R. L. Skovholt and G. M. Gozemba of AIPSD-GE were the Program Manager and Project Engineer, respectively.

Support was received from W. W. Thurlow, H. Swanson, M. Presz and A. Humber.

The report was submitted by the authors in October, 1976.

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1.0 INTRODUCTION

This is the final report for the development of the Solid State Vertical Scale Indicator (SSVSI). The program was initiated by Contract No. N62269-76-C-0109 under the sponsorship of the Naval Air Systems Command, Washington, D.C. and directed by the Naval Air Development Center, Warminster, Pennsylvania. The prime contractor is the General Electric Company, Aerospace Instruments and Product Support Department (AIPSD) located in Wilmington, Massachusetts.

The program involves the generation of a solid state approach to aircraft instrumentation. An earlier program involved the design, fabrication, testing and flight evaluation of a similar type of engine instrument group for the A6A aircraft. The successful evaluation of those units and the result of a design study for this application, initiated this program. Advances in the LED industry, and integrated circuit industry and the design concepts developed on this program make this type of instrument design practical today.

The LED display has seen limited application to military aircraft primarily due to the washout characteristics in high illumination. This sample demonstrates that satisfactory readability can be achieved in 10,000 ft.-candles of illumination. The improved performance is due to a combination of high efficiency LED, effective filtering and multiplexed drive circuitry. The display medium is red GaAsP. Similar readability is not practical at this time for yellow, green or blue LED's.

The instrument is a six channel instrument which is interchangeable with the electromechanical instruments on a shipset basis. The present aircraft instrumentation is three dual channel vertical tape instruments driven by a-c servos. The solid state design provides redundant numeric readouts in addition to the vertical tape. The instrument has weight, reliability and maintainability advantages in addition to displaying highly accurate information. MTBF estimates indicate that more than three times the reliability will be obtained from the new instrumentation as compared with the electromechanical.

The evaluation sample met or exceeded the design goals established in the Work Statement. It has successfully passed the required tests that were outlined in the proposal. The design is mechanically sound and the performance has been verified by tests. The delivered sample is intended to be flight evaluated. It will provide the pilot with superior readability of engine performance since it displays redundant numerics information in addition to vertical bargraphs.

2.0 INSTRUMENT DESIGN

The SSVSI instrument displays six channels of engine parameters. The display format for each channel is a linear vertical bargraph and a redundant 3½ digit numeric as shown in Figure 2-1. Red GaAsP light emitting diodes (LED) are used for the display. Engine Fuel Flow Rate (FF), Turbine Inlet Temperature (TIT) and RPM N_2 Turbine (RPM) are displayed for each of the two engines. All the signal conditioning, converters, drive circuitry and power supplies are contained within the instrument case. The case size is 4.5" wide, 5.0" high and 8.0" long. A brightness control knob is provided on the front panel to allow for the dimming of the bargraph and numerics. The instrument is front lighted by means of incandescent lamps and a two piece wedge.

2.1 Electrical Design

An instrument block diagram of the SSVSI is shown in Figure 2-2. Signal processing is performed independently for each of the six readouts. After a signal conditioning stage the bargraph and numerics signals are converted separately. To reduce the interconnection from the display and the circuit drivers, each bargraph and numeric display is connected in a 8 x 8 and 7 x 3 matrices respectively. A self test BIT is included to provide a predetermined bargraph and numeric indication derived from internally generated signals. The bargraph and numeric displays are powered from separate power supplies. The +12 and -12 volt circuit supplies are generated in each supply and are diode "ORED" to maintain adequate circuit power

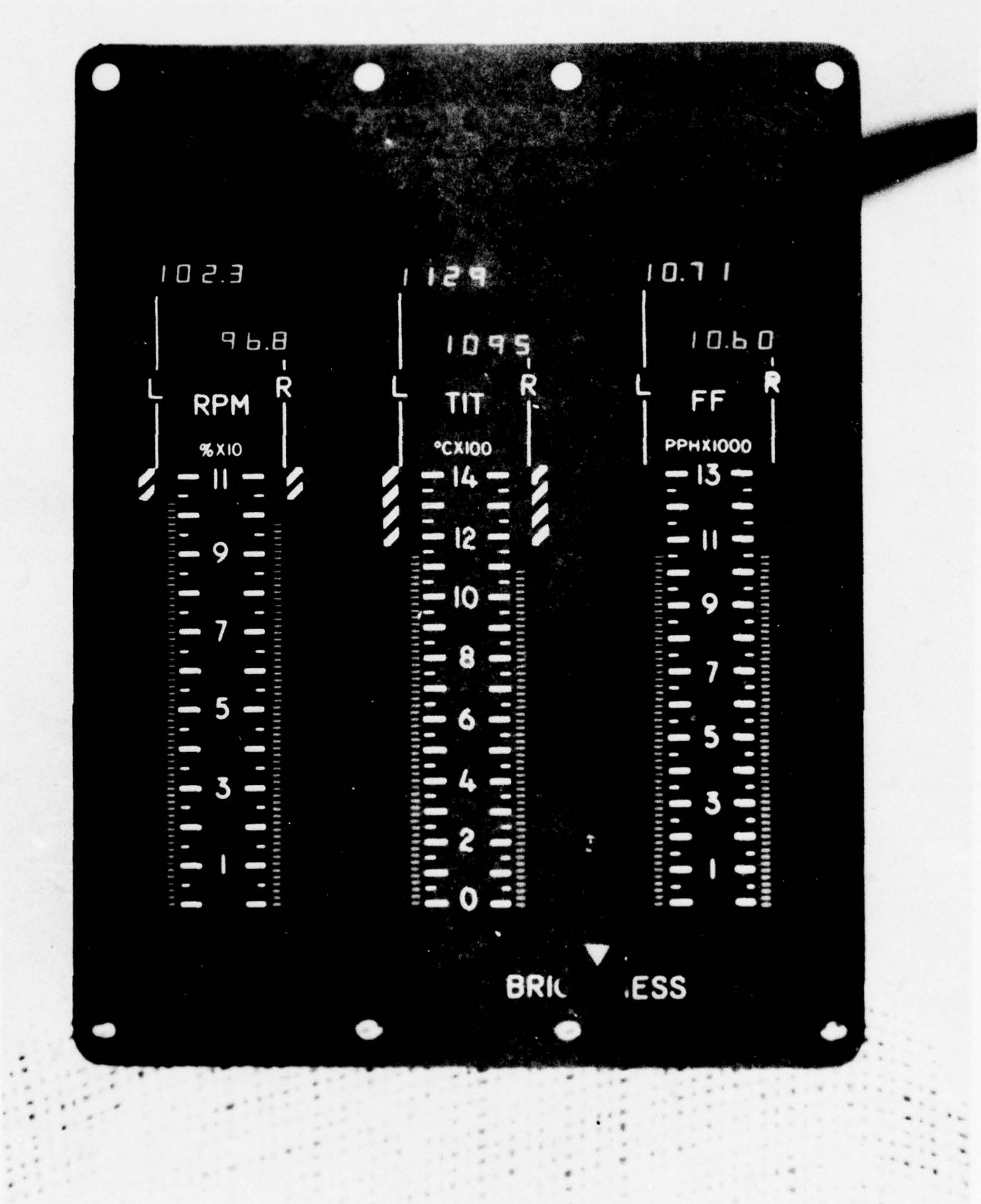

FIGURE 2-1 - FRONT VIEW APPEARANCE

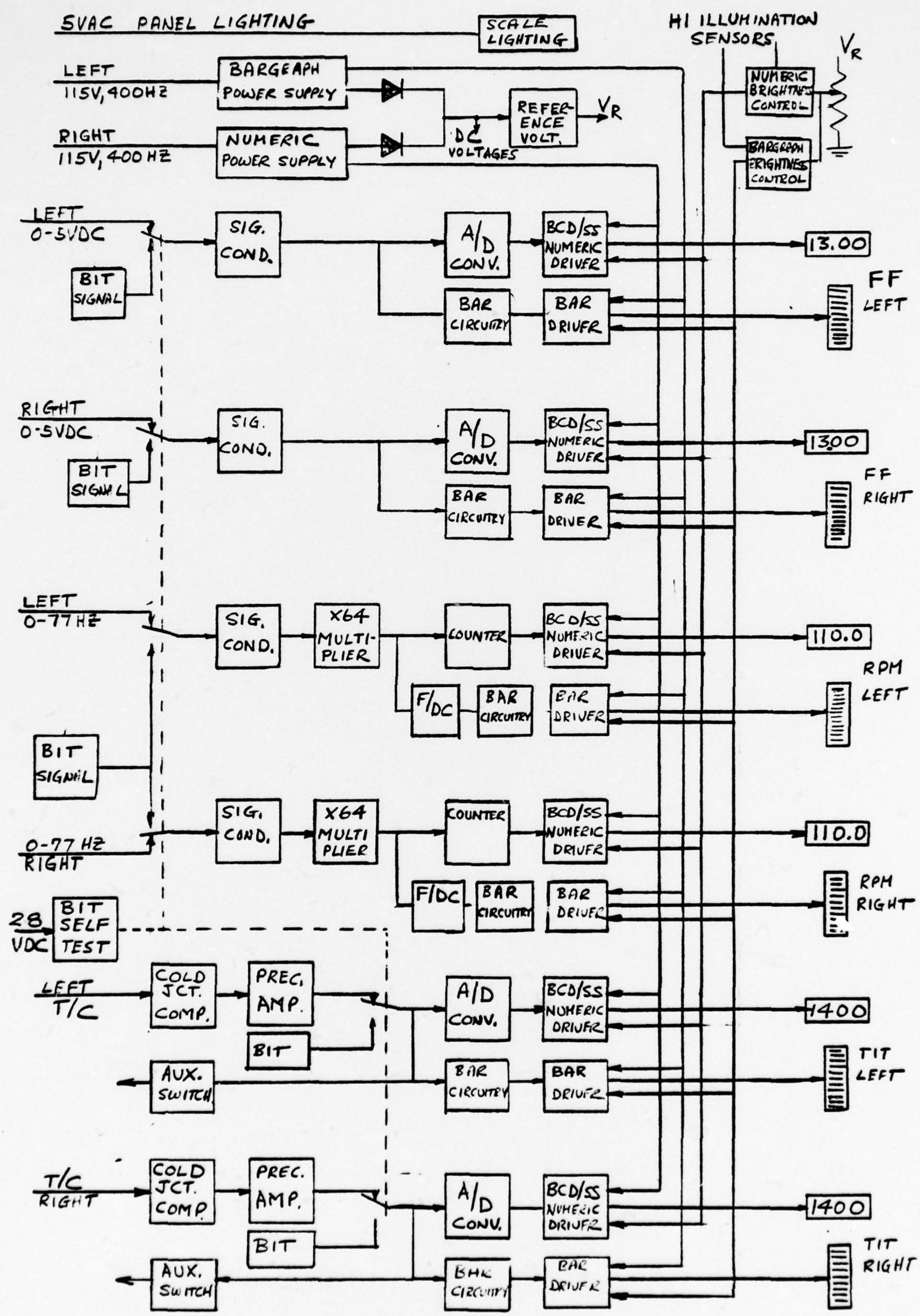

FIGURE 2-2 - INSTRUMENT BLOCK DIAGRAM

if one of the power supplies fails. A brightness control potentiometer allows for the continuous adjustment of the display intensity for low and high illumination light conditions. The bargraph and numerics have separately generated pulse width signals to control the duty cycle. A high illumination sensor activates a circuit that increases the intensity of the display during bright sunlight condition. The TIT indicator has a maximum temperature switch that closes when a TIT temperature of 1200°C is exceeded.

The circuitry is packaged on a functional basis with one board per dual readout. A total of six signal boards and two power supply boards are required for the total instrument.

2.1.1 RPM

The RPM signal in a sinusoidal voltage whose frequency is linearly proportional to % RPM. An input frequency of 77 Hz is required to indicate full scale of 110.0% RPM. The conversion is performed by counting the input frequency for an accurate period. Prior to the conversion the signal conditioner stage reduces the voltage level and squares up the waveform in a comparator stage. The low frequency is multiplied by 64 to allow for a count of 1100 in less than .23 seconds. The multiplication is accomplished by using a phased locked loop (PPL) that contains a voltage controlled oscillator (VCO), phase comparator and divide by 64 circuits. A crystal derived counting period, strobe, scan and reset pulses are required to control the counter. The counter provides a 3½ digit BCD signal that is time multiplexed. A BCD to seven segment (SS) conversion is required to control the numeric display. The numerics are time multiplexed and driven in a 3 x 7 matrix. The most significant digit is leading zero suppressed and indicates a blank until the readout exceeds three digits.

For the bargraph display the multiplied input frequency is converted to an appropriate DC level by a frequency to DC converter. The 64 element bargraph is connected in a 8 x 8 matrix and driven by eight current sinks and eight current sources. The DC voltage is converted to a control pulse wdith circuit by a servo controlled one shot. The source drivers are controlled in parallel from the control pulse width circuit in synchronism with the sink pulses. The sink drivers are sequentially controlled by a scanned pulse that drive up to 8 diodes at a time.

2.1.2 Turbine Inlet Temperature

The temperature signal is derived from an alumel chromel thermocouple and varies from 0-55.7 millivolt for 0-1400°C indication. The thermocouple leads are terminated in a cold junction compensation module inside of the instrument. The copper-thermocouple junction is sensed by resistors that become part of a compensation bridge. The signal input is connected to a pair of high impedance precision operational amplifiers to provide isolation. This allows for instrument operation if either thermocouple lead is grounded. The isolated signal is amplified to a 0-1.4V signal by another operational amplifier. The d-c signal voltage is converted to a digital BCD signal by a dual ramp integration A/D converter. The BCD signal is converted to a seven segment format to control the numeric display.

The amplified signal is utilized to drive the bargraph in the same manner as the RPM circuitry. The output switch is closed if the input temperature exceeds 1200°C. The d-c signal is compared to a reference level by an operational amplifier.

2.1.3 Fuel Flow

The fuel flow signal is a 0-5 VDC voltage for the 0-13,000 PPH indication. The signal conditioning stage reduces the voltage to 0-1.3 VDC. This d-c voltage is converted to a digital BCD signal by a dual ramp integration A/D converter. The output is a multiplexed BCD that is converted to a seven segment format to control the numeric display. The reduced signal voltage is utilized to drive the bargraph in the same manner as the RPM circuitry.

2.1.4 Power Supply

The instrument has two power supply boards and is partitioned per the power supply block diagram of Figure 2-3. One supply provides the power for all six numeric displays. The bargraph display power is split into two separate sources with the three left channels from one supply and the three right channels from the other. A failure of the one display power supply will result in either a loss of all numerics, left bargraphs or right bargraphs. With a single supply failure the six engine parameters will still be displayed.

The two supplies each generate +13V and -13 volts DC for the circuit power. The two +13V are diode "ORED" and the two -13V are diode ORED resulting in a single +12V and a single -12V for all the circuit power. A failure of one supply will still provide circuit power and maintain operation for the remaining display.

The brightness of the display is controlled by varying the duty cycle of the display driver. The pulse is separately generated for the bargraph and the numeric displays. The brightness level is set by the position of the adjust potentiometer. This d-c voltage is converted to a pulse width synchronized with the display scan.

A brightness increase circuit operates during high brightness setting and bright illumination. The display intensity is increased beyond the maximum manual setting at 10,000 ft.-cdle. A silicon phototransistor senses the ambient light intensity and initiates the increase above a set level. Below the 90% brightness control setting, the sensor is inhibited. This brightness increase allows for improved readability during high illumination and does not require the additional power dissipation during normal operation.

The power dissipation of the instrument is very dependent on the brightness control setting. At the night flying condition the required input power is less than 12 watts for all six channels. The maximum manual setting will result in 35 watts of dissipation. With a high brightness setting during bright illumination and full scale readings a total of 53 watts may be required.

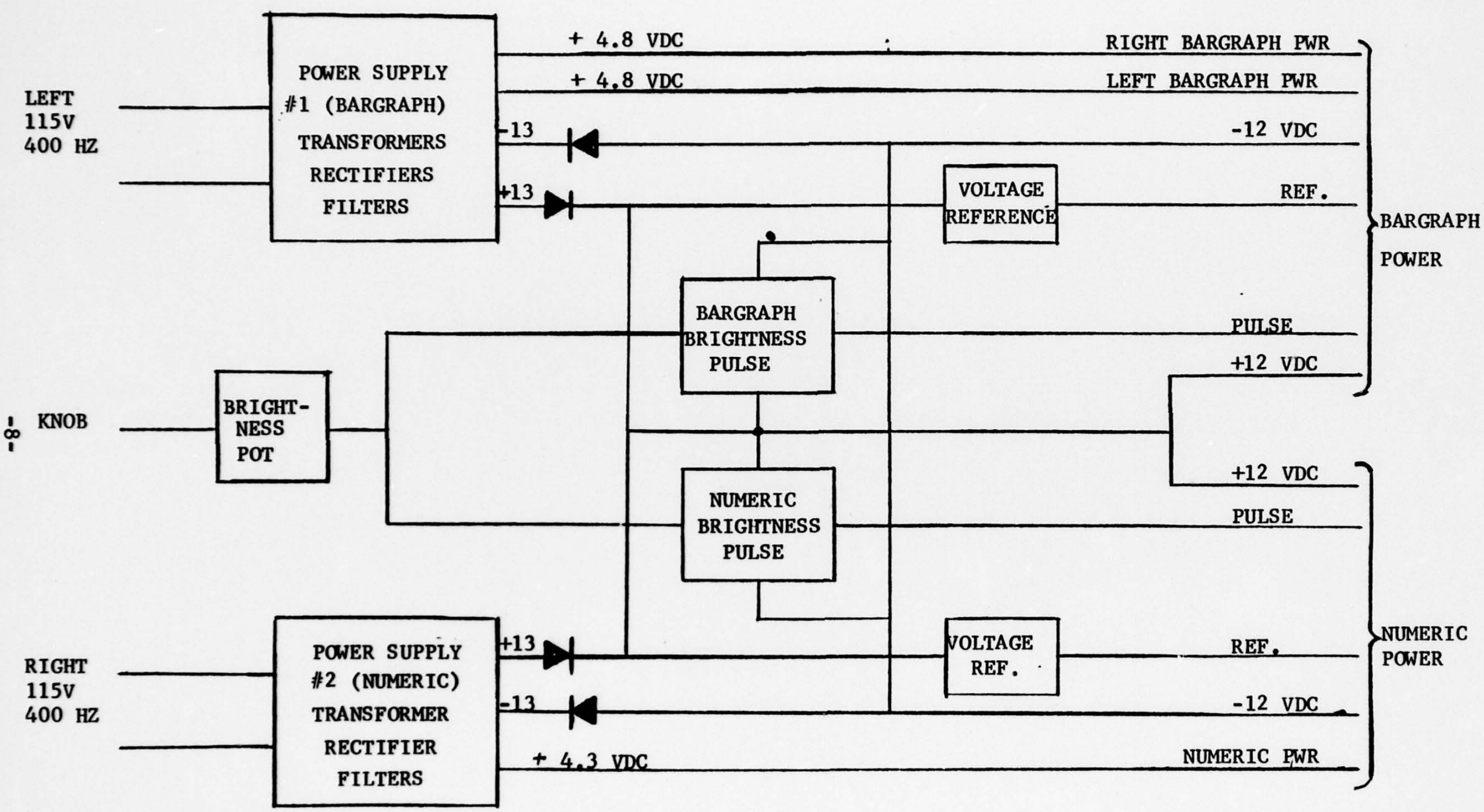

FIGURE 2-3 - POWER SUPPLY BLOCK DIAGRAM

2.2 LED Display

The displays used for this instrument are red light emitting diode (LED) as shown in Figure 2-4. The technology is gallium arsenide phospide (GaAsP) on a gallium arsenide (GaAs) substrate. A total of six bargraph modules and three numeric modules are required for each instrument. The displays are a custom design for this application.

The bar format consists of 64 diode chips that are mounted on a printed circuit board. The diodes are interconnected in a 8 x 8 matrix with 16 interface connections. The diodes are connected as common cathodes with the 8 cathodes (1-8, 9-16, etc.) and 8 anodes terminated at the output pins. The single in-line package (SIP) display has 16 plug-in pins on a standard .10" spacing. The package is symmetric so that the same part can be used for left and right side.

The digital display includes both left and right numerics for each parameter on a single board 1.3" x 1.3". Each number is a monolithic digit approximately .11" high and one sixteenth inch wide with a center to center spacing of .150". In a monolithic digit all segments are diffused into a single substrate and the spacing between segments can be minimized resulting in a more readable digit. The LED is a common cathode configuration and one cathode lead is brought out for each digit. The seven segments for each full digit are interconnected. The most significant digits (1) b and c anode segments are terminated on a separate pin. A total of 13 leads (including decimal point) are required for each 3½ digit readout. The dual in-line module has the 13 plug-in pins on each side with a standard .10" spacing. A red filter is placed over the diode chips to improve the readability in high illumination. The filter utilizes a red bandpass plus circular polarized layer with a diffused surface.

The digit and bargraph interconnection allows for the control of 526 elements with a total of 162 leads. An added benefit from the muliplexed technique is that LED's are more efficient in a pulsed duty cycle mode than in d-c operation.

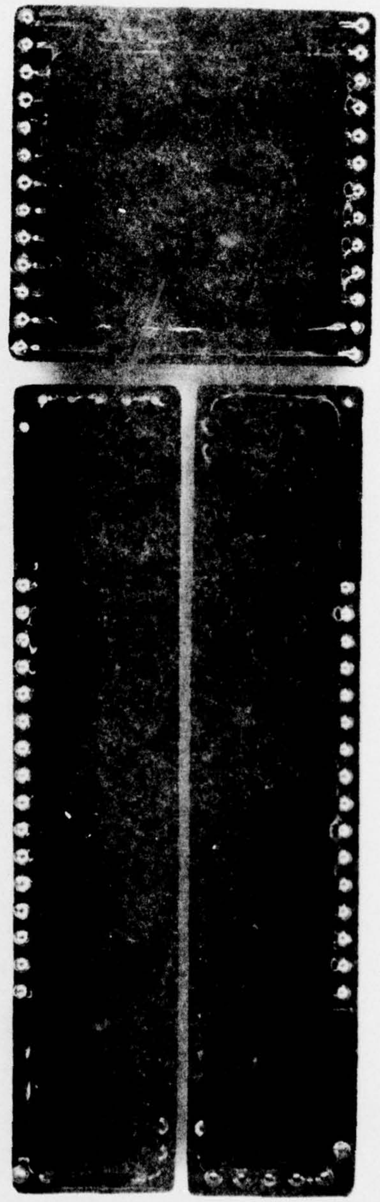

FIGURE 2-4 - LED DISPLAY

2.3 Mechanical Design

The six channel instrument is packaged in a single can that has outside dimensions of 4.5" wide, 5.0" high and 8.0" long. The solid state instrument is directly interchangeable with the present electromechanical instruments on a shipset basis without any panel or wiring changes.

The design is highly maintainable as Figure 2-5, the layout, indicates. The instrument is gasket sealed and therefore can be unsealed, repaired and resealed without a soldering operation. The design features plug-in boards, displays and lighting lamps. A total of six signal processing and two power supply circuit boards are required. The circuitry is partitioned on a functional basis and one board is necessary for each bargraph/numeric readout. The adjustment trimpots are all accessible when the rear plate is removed. One power supply is provided for the numeric readout and the other supply is required for the bargraph. A total of three power transformers are mounted over the boards. Two power transformers provide the current for the bargraph and the third provides the current for the numerics.

The complete display is packaged on nine plug-in modules. The bargraph requires six separate modules and the numerics requires three dual modules. The bargraph are a SIP modules and the numerics are DIP modules that are kept in place by tie down straps. A thin stainless steel scale with windows for the display area is placed over the display. The contrast enhancement is provided by a filter that is integral with the display module.

The display brightness can be varied by a adjustment knob on the instrument front. A single turn potentiometer with a bushing mount provides a variable DC voltage that is used to control the display intensity.

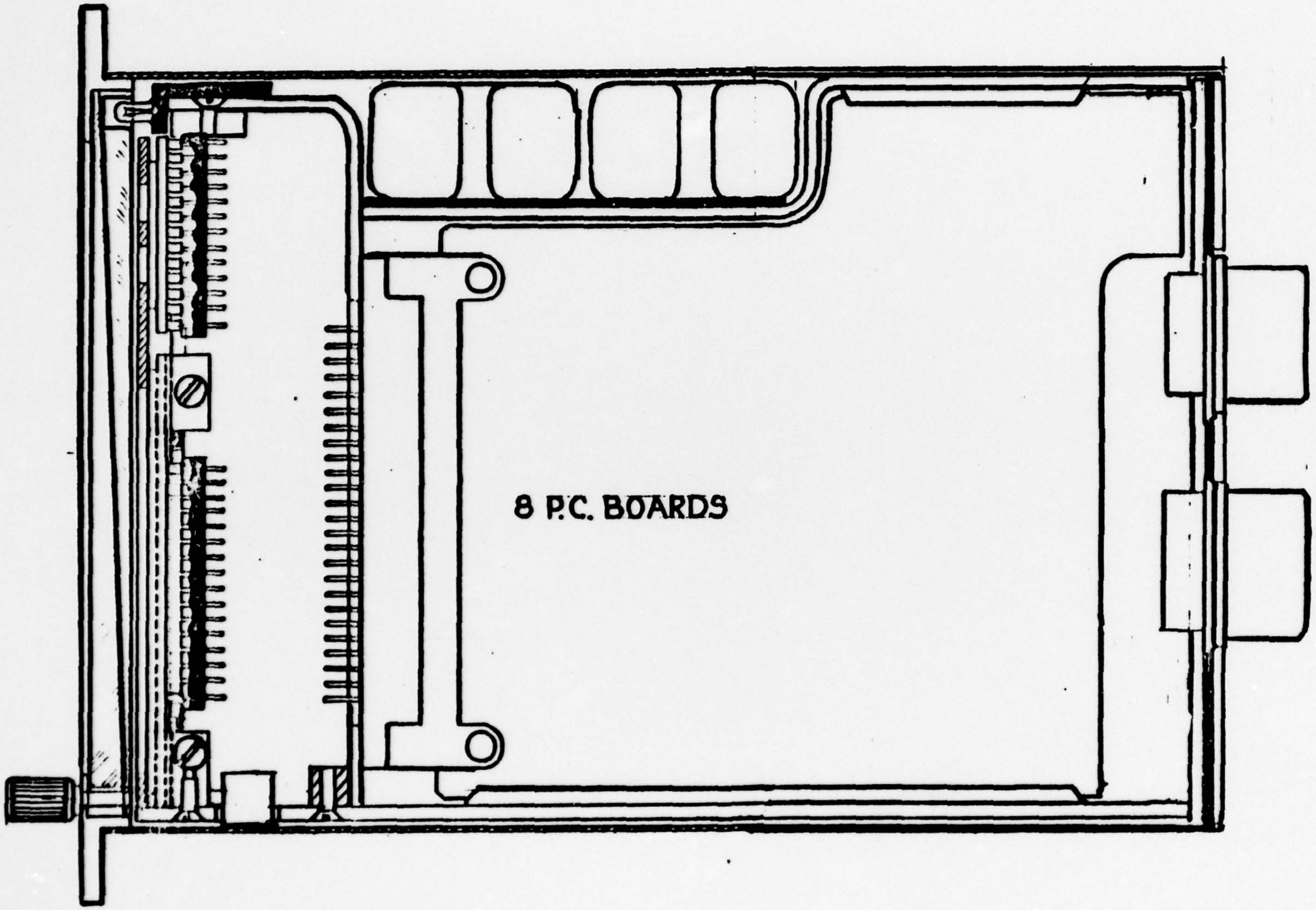

FIGURE 2-5 - SSVSI LAYOUT

2.3.1 Lighting

The SSVSI indicator utilizes front wedge lighting to light the nomenclature including the scale legend, numerals and carbration marks. The lighting is red integral conforming to MIL-C-25467C. A total of six T-1 type lamps are spaced across the top of the inner wedge. A cover wedge is used to make the wedge assembly symmetrical and keep the stray light to a minimum. Each side of both wedges are coated with antireflection coating conforming to MIL-C-14806A. The lighting intensity is controlled by adjusting the 5 VAC panel voltage.

2.4 MTBF Summary

Figure 2-5 is a summary of the preliminary reliability estimate for the SSVSI indicator. The failure rates are apportioned to the eight shop replaceable assemblies and display. The estimates were performed per MIL-STD-217B assuming a 70°C indicator temperature and aircraft inhabited environment. Based on the estimate of 4,485 hours a 2500 hour contract specified MTBF can be demonstrated with a high degree of confidence. This represents more than a 3:1 improvement over the 750 hour specified MTBF for the present electromechanical indicators.

3.0 EVALUATION TESTS

To establish flightworthiness for this instrument a testing program was performed. The instrument was subjected to tests such as scale error, high temperature, low temperature, power consumption, lighting, EMI, vibration, high illumination and temperature cycling. The instrument successfully passed these tests. A summary of some of the results is presented in Figure 3-1. A more detailed report DF76AEE163R was submitted as a separate item (A002b) under this contract. The scale error for room temperature, low temperature and high temperature is shown in Figure 3-2.

DESCRIPTION	*F/R - #/10^6 HOURS	QTY./INSTRUMENT	F/R TOTAL
TIT CIRCUITRY	18.46	2	36.92
RPM CIRCUITRY	17.28	2	34.56
FF CIRCUITRY	15.43	2	30.86
LED BARGRAPH	12.8	6	76.8
LED NUMERICS	5.0	6	30.0
POWER SUPPLY	6.9	2	13.8
		TOTAL	222.94

INSTRUMENT MTBF 4,485 HOURS

*ESTIMATE BASED ON MIL-STD-217B 70°C A/C INHABITED

FIGURE 2-5 - MTBF ESTIMATES

TEST	PROPOSED	ACTUAL
WEIGHT (LBS)	6.8	5.9
SIZE (IN)	4.5 x 5.0 x 8.0	4.49 x 5.00 x 7.98
POWER CONSUMPTION (WATTS)	25W NOMINAL 115V, 400 HZ 45W MAXIMUM 115V, 400 HZ	11.6, MIN. MANUAL 35, MAX. MANUAL ADJUST 52.9, 10,000 FT-CDLE
	6.5W MAX (LIGHTING) 5V, 400 HZ	3.5W
	2.0W MAX (BIT) 28 VDC	.1W
LIGHTING	INDIVIDUAL TEST OF MIL-I-25467	COLOR & BRIGHTNESS OK
EMI	CE03, CE04 & RE02, MIL-STD-462	PASSED
HI ILLUMINATION	READABLE AT 10,000 FT-CDLE ILLUMINATION WITH BRIGHTNESS SET AT MAXIMUM	PASSED
VIBRATION	.01" DA 5 HZ - 62 HZ 2G 62 HZ - 500 HZ	PASSED
BIT		RPM 80% $\pm$ 2% FF 9500 $\pm$ 100 PPH TIT 1300°C $\pm$ 20°C
ACCURACY	SEE FIGURE 3-2	PASSED
TEMPERATURE CYCLE	3 CYCLES -40°C TO +55°C	PASSED

FIGURE 3-1 - PERFORMANCE SUMMARY OF SSVSI

TEST POINT % RPM	IDEAL INPUT (HZ)	ERROR (% RPM) 25°C L	25°C R	-40°C L	-40°C R	+55°C L	+55°C R
40	28	+ .03	+ .03	+ .03	+ .04	0	+ .14
70	49	+ .03	+ .04	+ .06	+ .04	+ .28	+ .28
80	56	+ .04	0	+ .04	+ .06	0	0
90	63	+ .01	+ .03	+ .07	+ .03	+ .14	+ .14
100	70	+ .09	+ .01	+ .06	+ .04	0	0
110	77	+ .01	+ .01	+ .06	+ .03	0	0
	LIMIT (± % RPM)	.2	.2	.4	.4	.3	.3
TEST POINT °C	**IDEAL INPUT (MV)**	**ACTUAL ERROR °C 25°C L**	**25°C R**	**-40°C L**	**-40°C R**	**+55°C L**	**+55°C R**
400	15.33	0	0	+ 3.2	- 1.0	+ 2.72	+ 4.95
600	23.31	- 2.5	- 3.5	+ .5	- 4.5	- .25	+ 1.48
800	31.41	- 1.5	- 3.0	+ 2.2	- 4.5	- .74	+ 1.48
1000	39.50	- 1.0	- 2.7	+ 3.0	- 4.7	- 1.24	+ .49
1200	47.57	- 1.0	- 3.2	+ 3.2	- 5.9	- 1.73	- .74
1400	55.71	+ 2.0	- 1.7	+ 6.4	- 4.0	- 1.48	+ .74
	LIMIT 400,600 (±°C)	25	25	50	50	38	38
	800-1400 (±°C)	5	5	10	10	8	8
TEST POINT FF	**IDEAL INPUT (VOLTS)**	**ACTUAL ERROR PPH 25°C L**	**25°C R**	**-40°C L**	**-40°C R**	**+55°C L**	**+55°C R**
1000	.385	+13.0	0	+ 2.6	+10.4	+31.2	+10.4
3000	1.154	0	+ 5.2	- 2.6	+15.6	+23.4	+ 5.2
5000	1.923	- 7.8	- 2.6	+ 2.6	+20.8	+18.2	- 2.6
7000	2.692	-10.4	-13.0	0	+18.2	+20.8	-10.4
11000	4.231	-18.2	- 5.2	+15.6	+33.2	+28.6	-18.2
13000	5.000	-18.2	- 2.6	+20.8	+41.6	+28.6	-26.0
	LIMIT (± PPH)	26	26	52	52	39	39

FIGURE 3-2 - TEMPERATURE TEST DATA

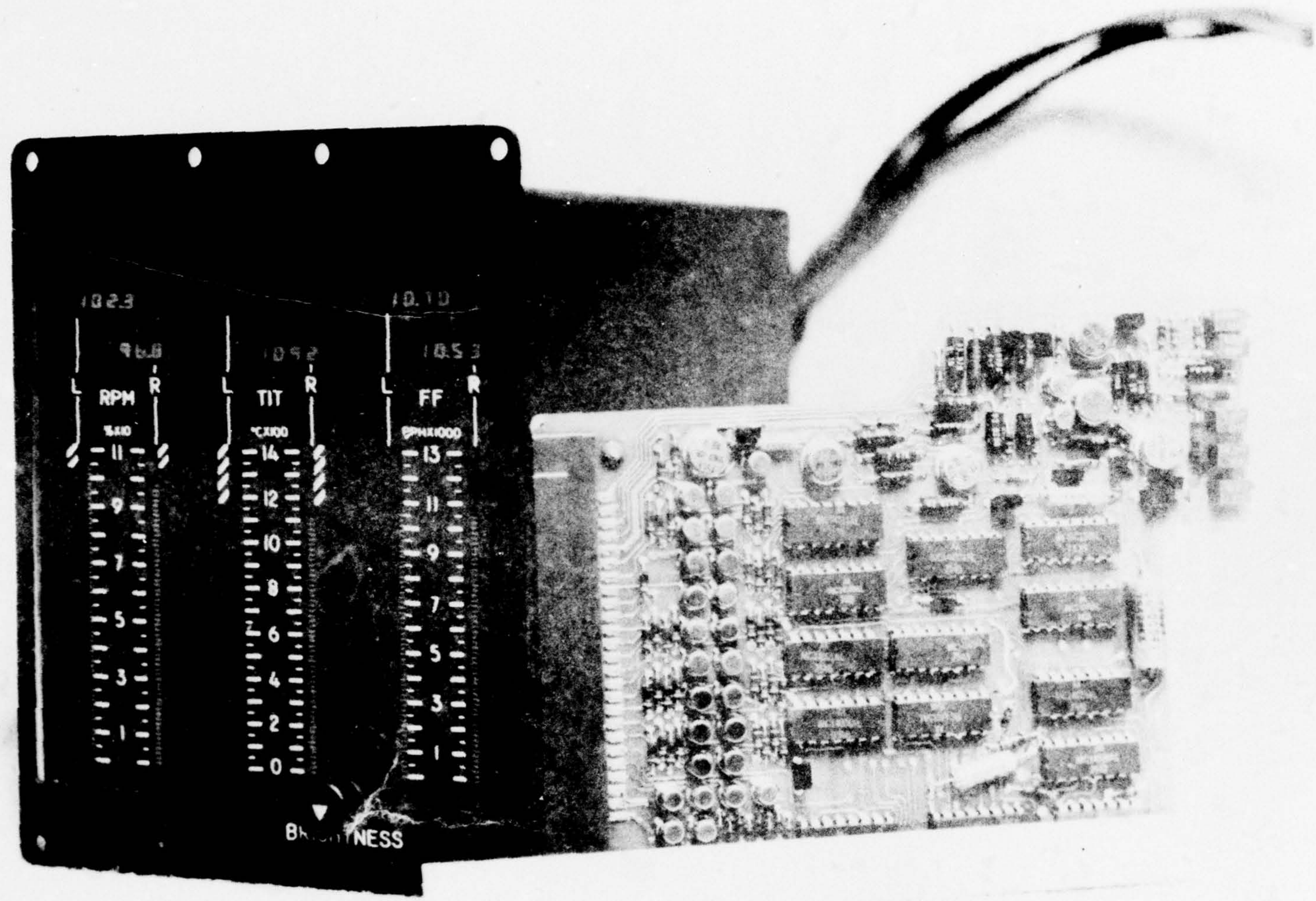

FIGURE 4-1 - SSVSI RIGHT CORNER VIEW

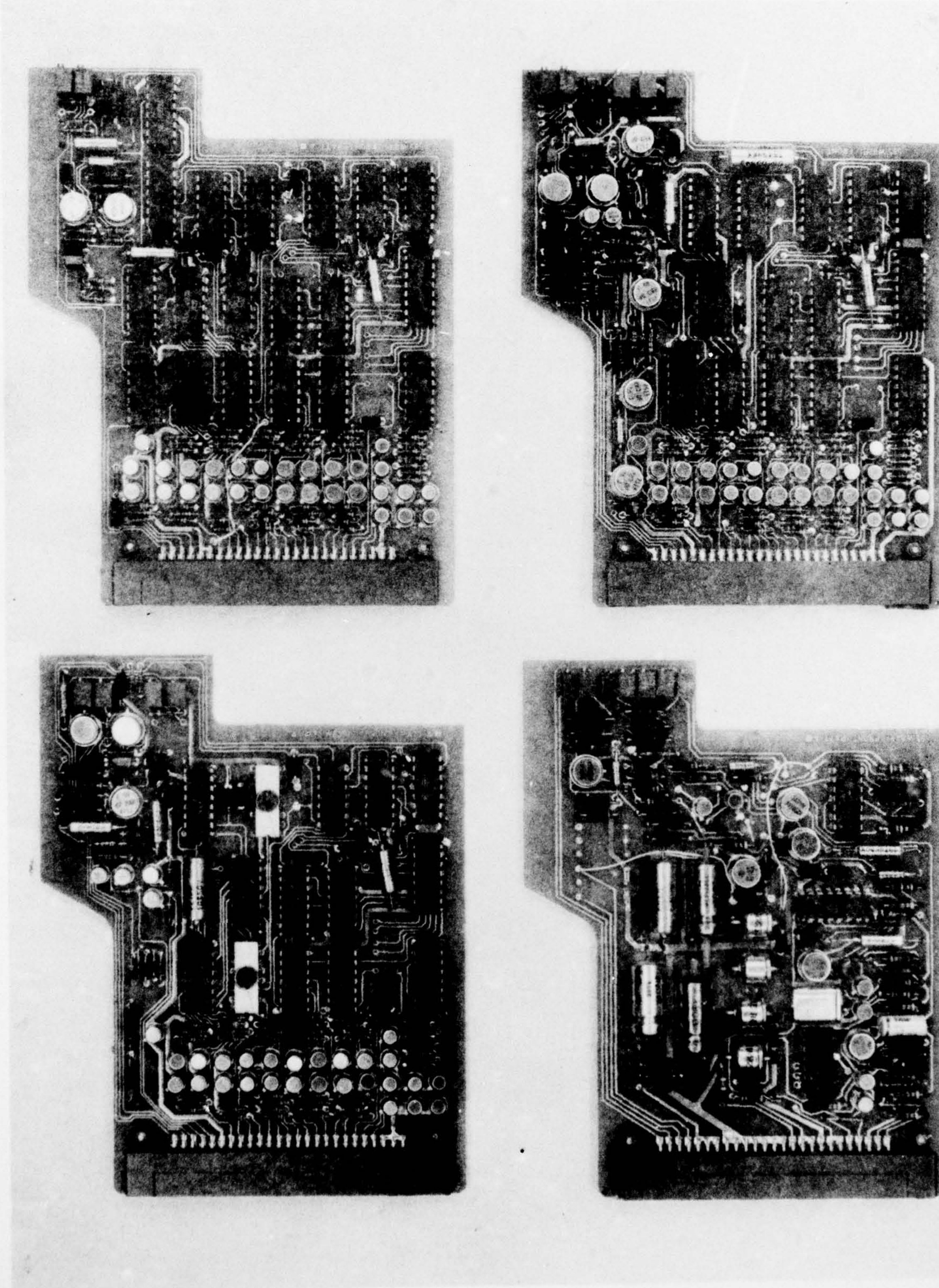

FIGURE 4-2 - SSVSI CIRCUIT BOARDS

4.0 HARDWARE PICTURES

Figure 4-1 shows a right side corner view with the instrument operating and the left TIT circuit board removed. In the aircraft the instrument is positioned over the pilot's left knee.

Figure 4-2 is a photograph of half of the instruments' circuit boards. Starting in the upper left hand corner and rotating clockwise the boards are the FF, RPM, TIT and power supply. The full instrument requires an additional set (8 boards total).

5.0 CONCLUSIONS

The design features and appearance of this display make it a practical display for red lighted aircraft application. This design is highly maintainable and does not require a skilled technician for repair. The design offers plug-in circuit boards, LED display and lighting lamps. This solid state display is shock and vibration resistant, operates over a wide temperature range, has a wide viewing angle and has a pleasing uniform appearance. Red LED are suitable for high illumination applications since the contrast ratio and viewability can be dramatically enhanced with red filters.

The functional circuit partitioning make it easy to isolate defective modules. The redundant features of bargraph/numeric, two power supplies, and separate signal processing after the signal conditioning would provide indication with most of the failure modes.

6.0 RECOMMENDATIONS

The performance of the evaluation sample and attractive features offered by this type of display indicates that future work should be a qualification program. This instrument sample design could be implemented into a production design with only minor design modification. The concepts developed could also be utilized on other bargraph designs.

The recommended program would include the fabrication of three units for a reliability demonstration test and two units for environmental tests. The major tasks that are required are:

a. Generate full documentation

b. Improve vibration immunity

c. Develop an O-ring sealed can with wedge lighting

d. Tool the LED displays

e. Fabricate five instruments

f. Perform reliability demonstration test

g. Perform environmental tests

The instruments will be interchangeable with the present electromechanical design on the instrument level. The qualification tests will demonstrate the design integrity for aircraft application.

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